

Chapter 3

Amplitude Modulation Fundamentals

Topics Covered

- 3-1: AM Concepts
- 3-2: Modulation Index and Percentage of Modulation
- 3-3: Sidebands and the Frequency Domain
- 3-4: AM Power
- 3-5: Single-Sideband Modulation
- 3-6: Classification of Radio Emissions

3-1: AM Concepts

- In the modulation process, the voice, video, or digital signal modifies another signal called the carrier.
- In **amplitude modulation (AM)** the information signal varies the amplitude of the carrier sine wave.
- The instantaneous value of the carrier amplitude changes in accordance with the amplitude and frequency variations of the modulating signal.
- An imaginary line called the **envelope** connects the positive and negative peaks of the carrier waveform.

3-1: AM Concepts

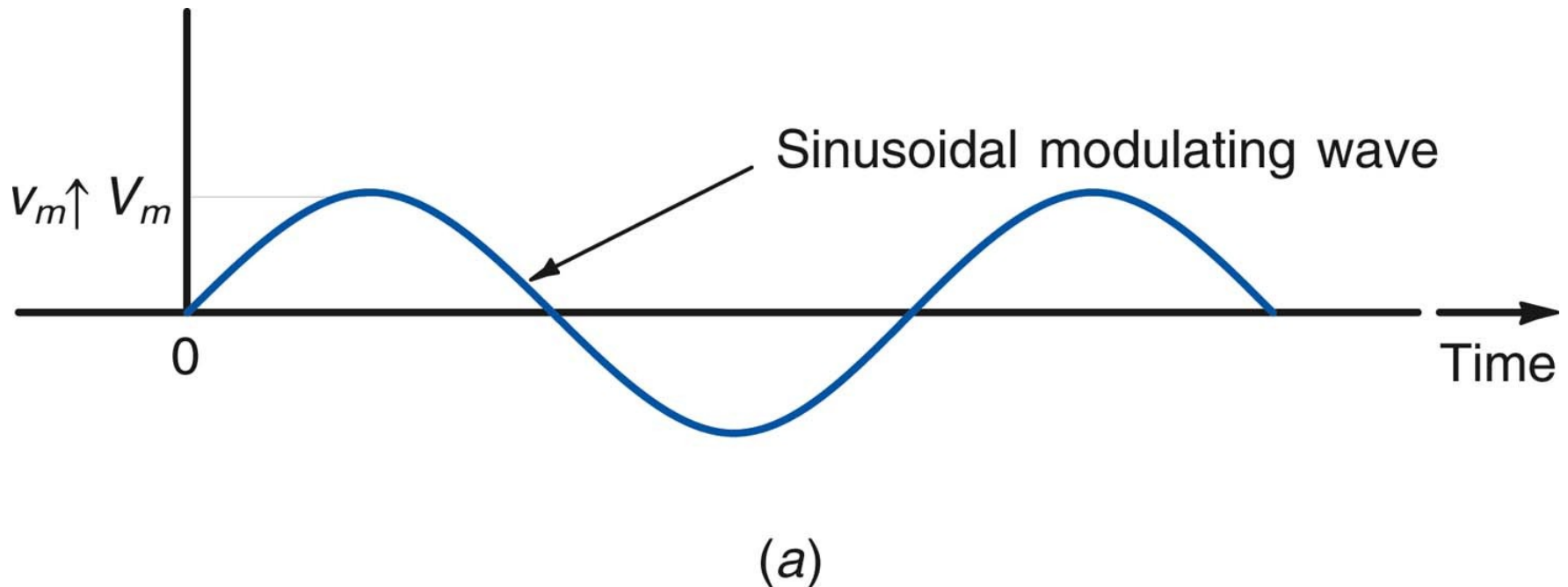
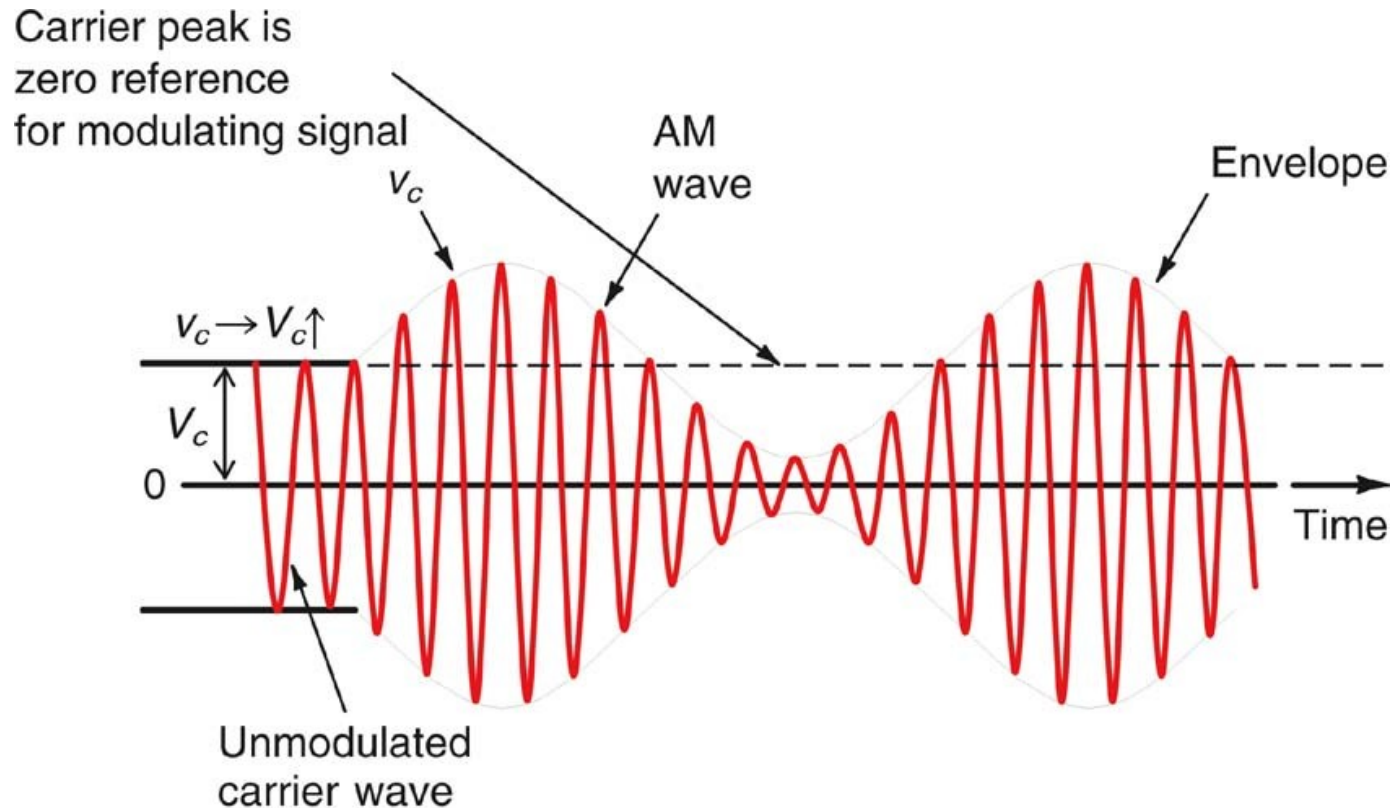


Figure 3-1: Amplitude modulation. (a) The modulating or information signal.

3-1: AM Concepts



(b)

Figure 3-1: Amplitude modulation. (b) The modulated carrier.

3-1: AM Concepts

- In AM, it is particularly important that the peak value of the modulating signal be less than the peak value of the carrier.

$$V_m < V_c$$

- **Distortion** occurs when the amplitude of the modulating signal is greater than the amplitude of the carrier.
- A modulator is a circuit used to produce AM. Amplitude modulators compute the product of the carrier and modulating signals.

3-1: AM Concepts

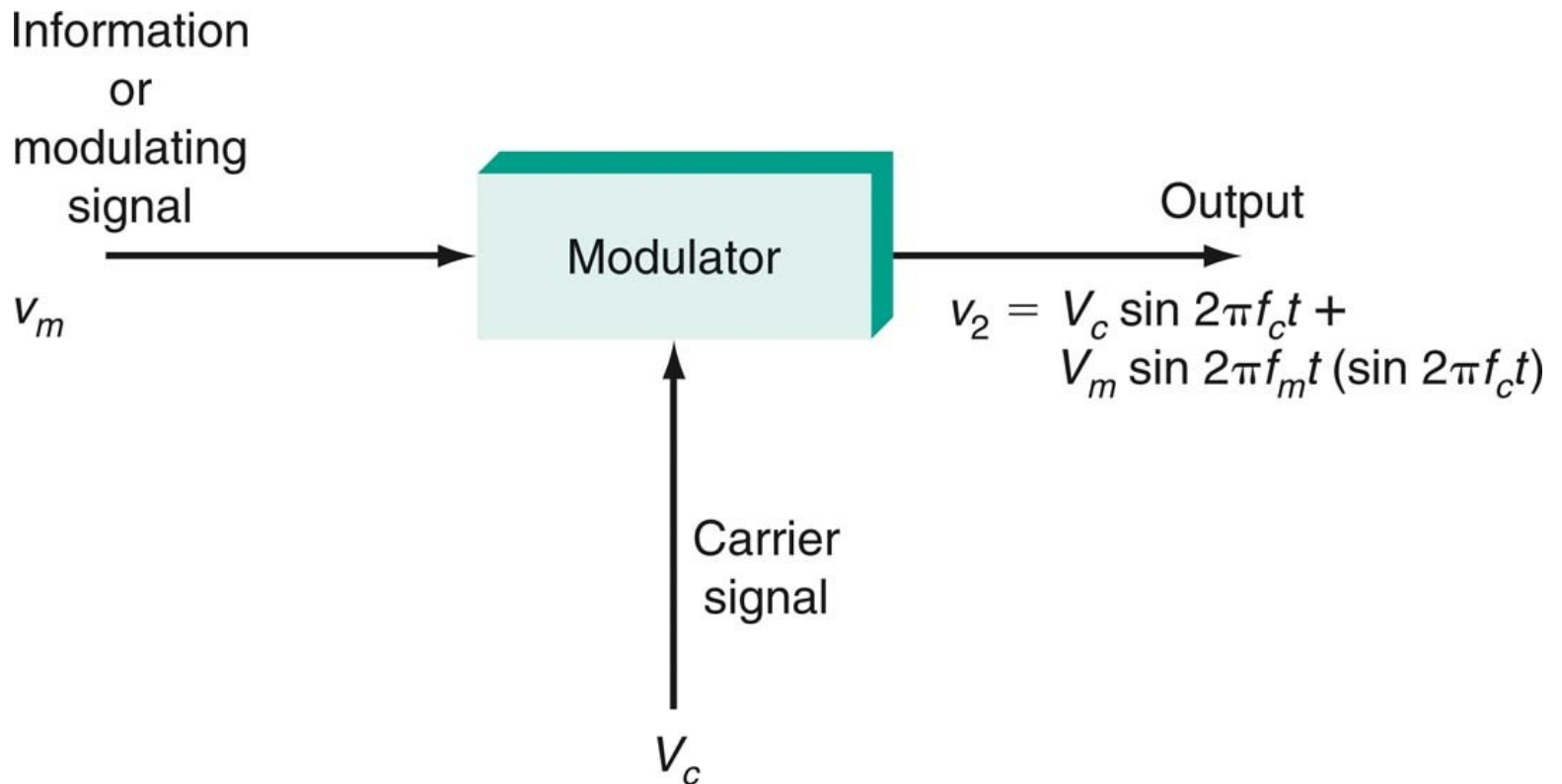


Figure 3-3: Amplitude modulator showing input and output signals.

3-2: Modulation Index and Percentage of Modulation

- The **modulation index (m)** is a value that describes the relationship between the amplitude of the modulating signal and the amplitude of the carrier signal.

$$m = V_m / V_c$$

- This index is also known as the **modulating factor** or **coefficient**, or the **degree of modulation**.
- Multiplying the modulation index by 100 gives the percentage of modulation.

3-2: Modulation Index and Percentage of Modulation

Overmodulation and Distortion

- The modulation index should be a number between 0 and 1.
- If the amplitude of the modulating voltage is higher than the carrier voltage, m will be greater than 1, causing distortion.
- If the distortion is great enough, the intelligence signal becomes unintelligible.

3-2: Modulation Index and Percentage of Modulation

Overmodulation and Distortion

- Distortion of voice transmissions produces garbled, harsh, or unnatural sounds in the speaker.
- Distortion of video signals produces a scrambled and inaccurate picture on a TV screen.

3-2: Modulation Index and Percentage of Modulation

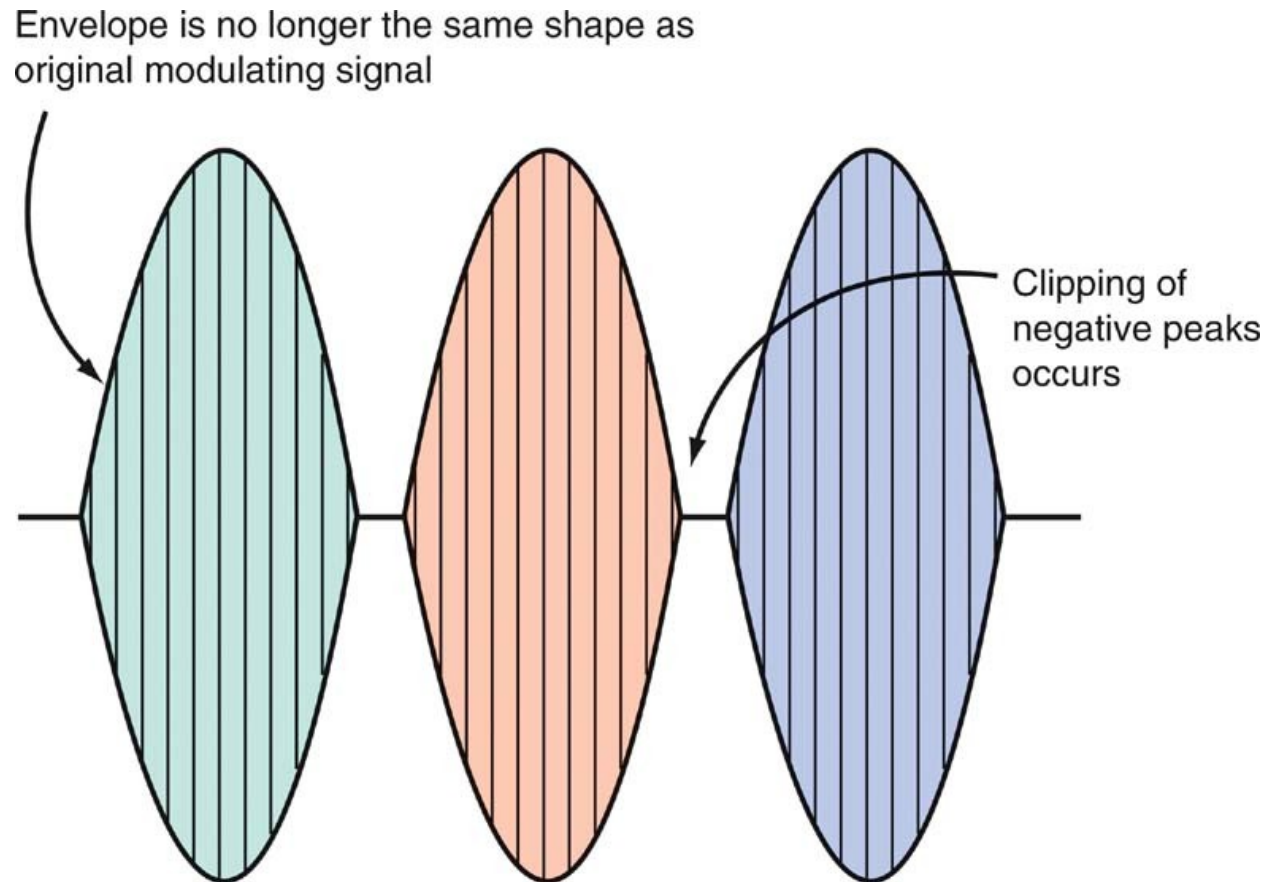


Figure 3-4: Distortion of the envelope caused by overmodulation where the modulating signal amplitude V_m is greater than the carrier signal V_c .

3-2: Modulation Index and Percentage of Modulation

Percentage of Modulation

- The modulation index is commonly computed from measurements taken on the composite modulated waveform.
- Using oscilloscope voltage values:

$$Vm = \frac{V_{\max} - V_{\min}}{2}$$

- The amount, or depth, of AM is then expressed as the percentage of modulation ($100 \times m$) rather than as a fraction.

3-2: Modulation Index and Percentage of Modulation

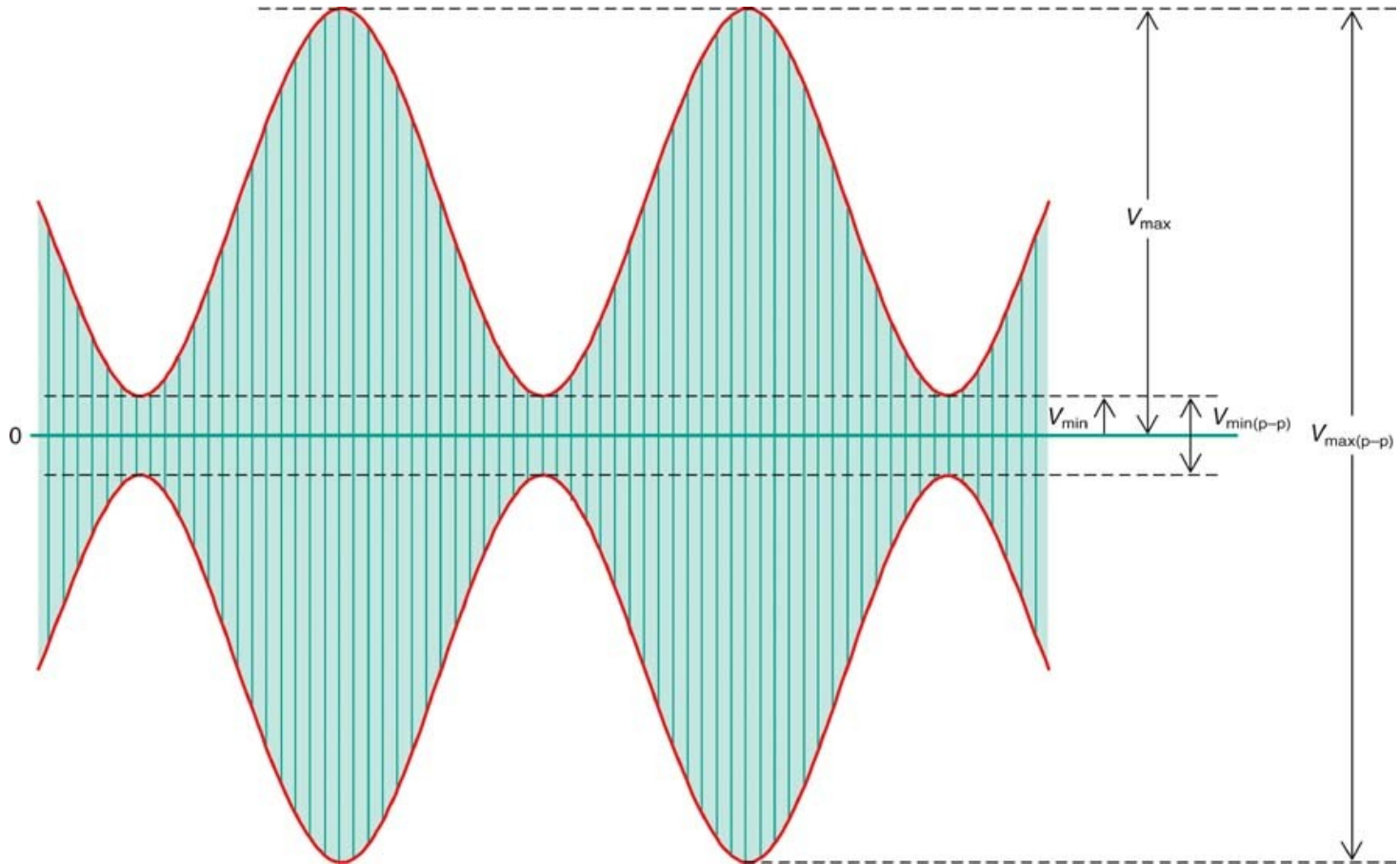


Figure 3-5: AM wave showing peaks (V_{\max}) and troughs (V_{\min}).

3-3: Sidebands and the Frequency Domain

- **Side frequencies**, or **sidebands** are generated as part of the modulation process and occur in the frequency spectrum directly above and below the carrier frequency.

3-3: Sidebands and the Frequency Domain

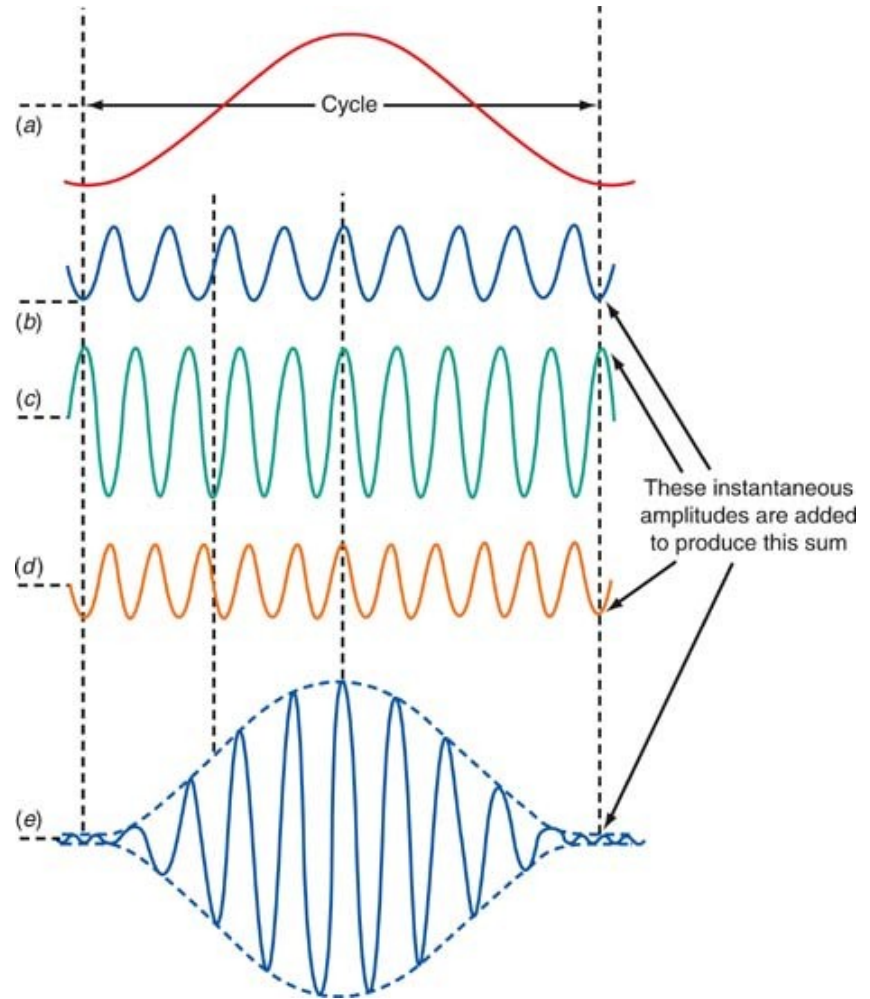
Sideband Calculations

- Single-frequency sine-wave modulation generates two sidebands.
- Complex wave (e.g. voice or video) modulation generates a range of sidebands.
- The upper sideband (f_{USB}) and the lower sideband (f_{LSB}) are calculated:

$$f_{\text{USB}} = f_c + f_m \text{ and } f_{\text{LSB}} = f_c - f_m$$

3-3: Sidebands and the Frequency Domain

Figure 3-6: The AM wave is the algebraic sum of the carrier and upper and lower sideband sine waves. (a) Intelligence or modulating signal. (b) Lower sideband. (c) Carrier. (d) Upper sideband. (e) Composite AM wave.



3-3: Sidebands and the Frequency Domain

Frequency-Domain Representation of AM

- Observing an AM signal on an oscilloscope, you see only amplitude variations of the carrier with respect to time.
- A plot of signal amplitude versus frequency is referred to as **frequency-domain display**.
- A spectrum analyzer is used to display the frequency domain as a signal.
- Bandwidth is the difference between the upper and lower sideband frequencies.

$$BW = f_{\text{USB}} - f_{\text{LSB}}$$

3-3: Sidebands and the Frequency Domain

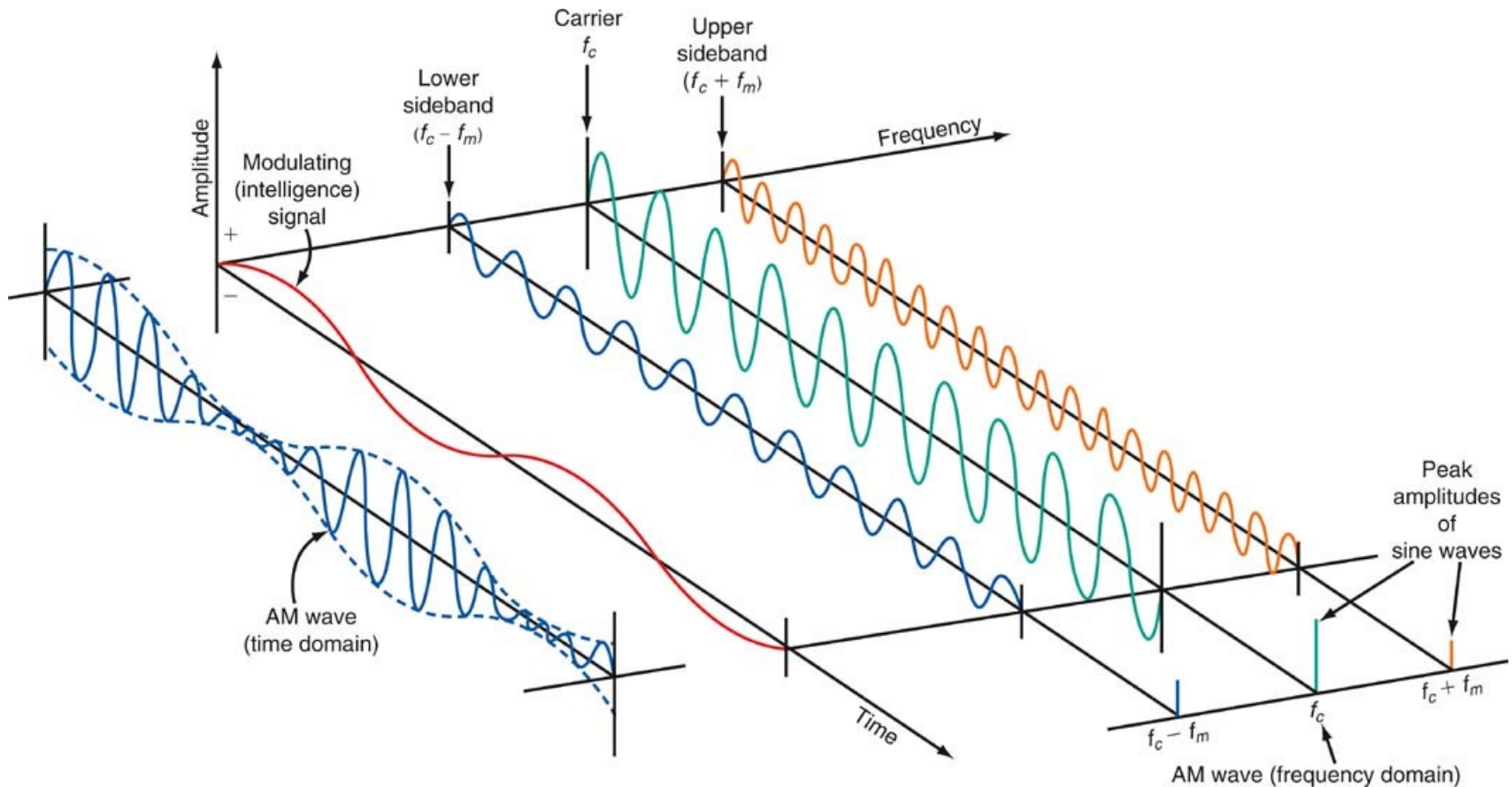


Figure 3-8: The relationship between the time and frequency domains.

3-3: Sidebands and the Frequency Domain

Frequency-Domain Representation of AM

- **Example:**

A standard AM broadcast station is allowed to transmit modulating frequencies up to 5 kHz. If the AM station is transmitting on a frequency of 980 kHz, what are sideband frequencies and total bandwidth?

$$f_{\text{USB}} = 980 + 5 = 985 \text{ kHz}$$

$$f_{\text{LSB}} = 980 - 5 = 975 \text{ kHz}$$

$$\text{BW} = f_{\text{USB}} - f_{\text{LSB}} = 985 - 975 = 10 \text{ kHz}$$

$$\text{BW} = 2 (5 \text{ kHz}) = 10 \text{ kHz}$$

3-3: Sidebands and the Frequency Domain

Pulse Modulation

- When complex signals such as pulses or rectangular waves modulate a carrier, a broad spectrum of sidebands is produced.
- A modulating square wave will produce sidebands based on the fundamental sine wave as well as the third, fifth, seventh, etc. harmonics.
- Amplitude modulation by square waves or rectangular pulses is referred to as **amplitude shift keying (ASK)**.
- ASK is used in some types of data communications.

3-3: Sidebands and the Frequency Domain

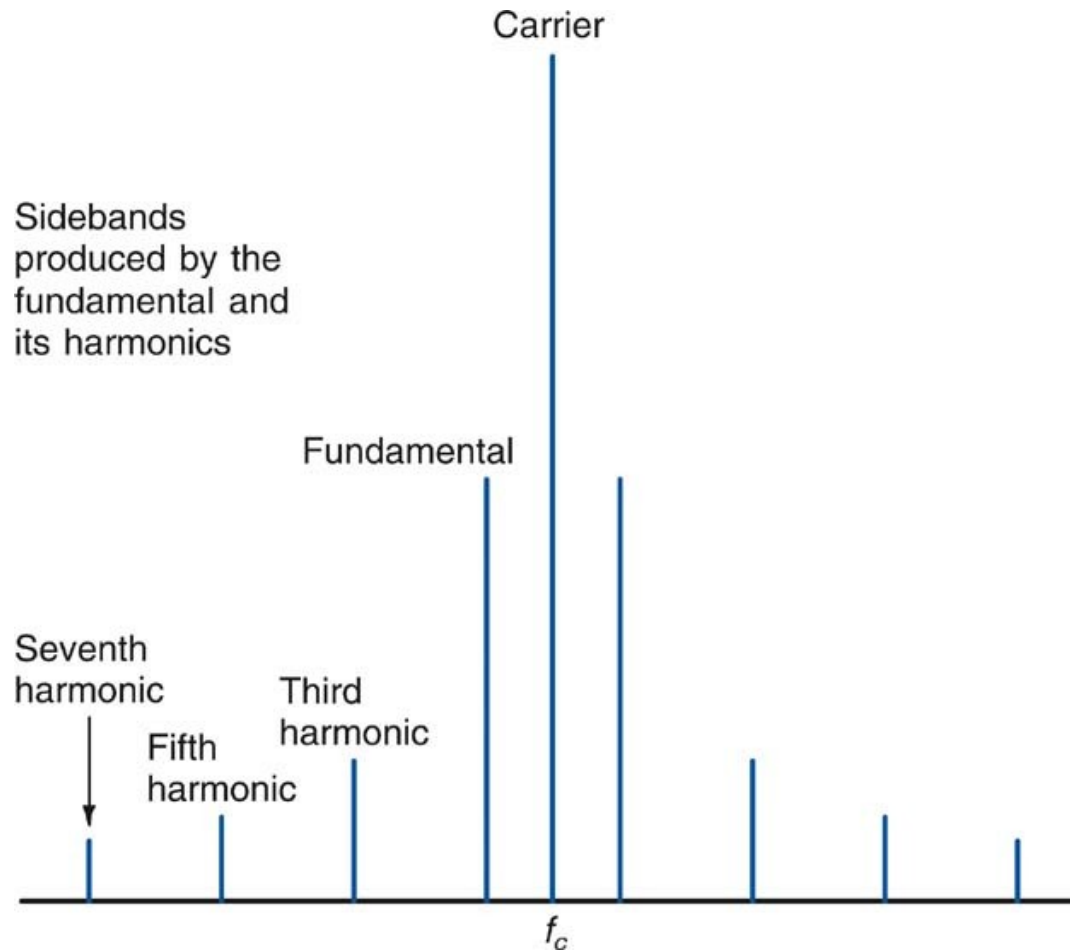


Figure 3-11: Frequency spectrum of an AM signal modulated by a square wave.

3-3: Sidebands and the Frequency Domain

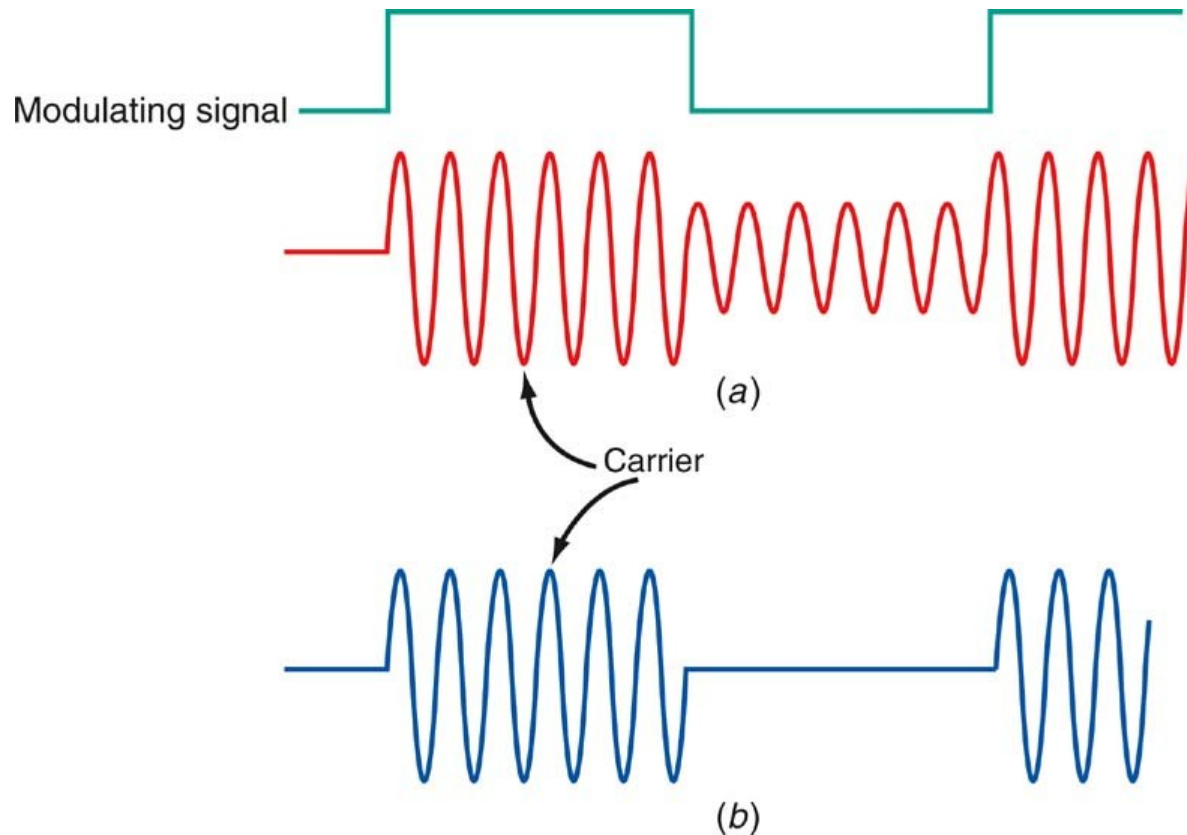


Figure 3-12: Amplitude modulation of a sine wave carrier by a pulse or rectangular wave is called amplitude-shift keying. (a) Fifty percent modulation. (b) One hundred percent modulation.

3-3: Sidebands and the Frequency Domain

Pulse Modulation

- **Continuous-wave (CW)** transmission can be achieved by turning the carrier off and on, as in Morse code transmission.
- Continuous wave (CW) transmission is sometimes referred to as **On-Off keying (OOK)**.
- **Splatter** is a term used to describe harmonic sideband interference.

AM Mathematical description

- Let carrier wave is $v_c = V_c \sin 2\pi f_c t$
- And single audio tone as modulating signal is

$$v_m = V_m \sin 2\pi f_m t$$

- So modulated signal,
 $v_{AM} = V_c \sin 2\pi f_c t + V_m \sin 2\pi f_m t (\sin 2\pi f_c t)$

AM Mathematical description

- Making use of the trigonometric identity:

$$(\sin X)(\sin Y) = \frac{1}{2} \cos(X - Y) - \frac{1}{2} \cos(X + Y)$$

- The equation describing the amplitude-modulated wave may be written as:

$$v_{AM} = V_c \sin 2\pi f_c t + \frac{V_m}{2} \cos 2\pi t (f_c - f_m) - \frac{V_m}{2} \cos 2\pi t (f_c + f_m)$$

$$v_{AM} = V_c \sin 2\pi f_c t + \frac{V_m}{2} \cos 2\pi t (f_{LSB}) - \frac{V_m}{2} \cos 2\pi t (f_{USB})$$

AM Mathematical description

- Modulation factor, $m = \frac{V_m}{V_c}$
- V_m = peak value of modulating signal,
- V_c = peak value of unmodulated carrier
- When expressed as a percentage, this is known as the percent modulation, M .

$$M = \frac{V_m}{V_c} \times 100$$

3-4: AM Power

- In radio transmission, the AM signal is amplified by a power amplifier.
- A radio antenna has a characteristic impedance that is ideally almost pure resistance.
- The AM signal is a composite of the carrier and sideband signal voltages.
- Each signal produces power in the antenna.
- Total transmitted power (P_T) is the sum of carrier power (P_c) and power of the two sidebands (P_{USB} and P_{LSB}).

3-4: AM Power

- The transmitted power, $P_T = P_C + P_{LSB} + P_{USB}$
- Compared to the original AM equation

$$v_{AM} = V_c \sin 2\pi f_c t + \frac{V_m}{2} \cos 2\pi t (f_{LSB}) - \frac{V_m}{2} \cos 2\pi t (f_{USB})$$

- Remember that V_m and V_c are the peak value of the modulating signal and carrier respectively.
- The rms carrier and sideband voltages are then

$$v_{AM} = \frac{V_c}{\sqrt{2}} \sin 2\pi f_c t + \frac{V_m}{2\sqrt{2}} \cos 2\pi t (f_c - f_m) - \frac{V_m}{2\sqrt{2}} \cos 2\pi t (f_c + f_m)$$

3-4: AM Power

- The power in the carrier and sidebands can be calculated by using the power formula

- Transmitted power, $P = \frac{V^2}{R}$

$$P_T = \frac{\left(\frac{V_c}{\sqrt{2}}\right)^2}{R} + \frac{\left(\frac{V_m}{2\sqrt{2}}\right)^2}{R} + \frac{\left(\frac{V_m}{2\sqrt{2}}\right)^2}{R}$$
$$P_T = \frac{V_c^2}{2R} + \frac{V_m^2}{8R} + \frac{V_m^2}{8R} = \frac{V_c^2}{2R} + \frac{V_m^2}{4R}$$

3-4: AM Power

- If we express the sideband powers in term of the carrier power, the total power becomes

$$P_T = \frac{V_c^2}{2R} + \frac{m^2 V_c^2}{8R} + \frac{m^2 V_c^2}{8R}$$

$$P_T = \frac{V_c^2}{2R} \left(1 + \frac{m^2}{4} + \frac{m^2}{4} \right)$$

$$P_T = P_c \left(1 + \frac{m^2}{2} \right)$$

3-4: AM Power

- When the percentage of modulation is less than the optimum 100, there is much less power in the sidebands.
- Practically output power can be calculated by using the formula

$$P_T = (I_T)^2 R$$

where I_T is measured RF current and R is antenna impedance

3-4: AM Power

- The greater the percentage of modulation, the higher the sideband power and the higher the total power transmitted.
- Power in each sideband is calculated

$$P_{SB} = P_{LSB} = P_{USB} = P_c m^2 / 4$$

- Maximum power appears in the sidebands when the carrier is 100 percent modulated.

3-5: Single-Sideband Modulation

- In amplitude modulation, two-thirds of the transmitted power is in the carrier, which conveys no information.
- Signal information is contained within the sidebands.
- **Single-sideband (SSB)** is a form of AM where the carrier is suppressed and one sideband is eliminated.

3-5: Single-Sideband Modulation

DSB Signals

- The first step in generating an SSB signal is to suppress the carrier, leaving the upper and lower sidebands.
- This type of signal is called a **double-sideband suppressed carrier (DSSC)** signal. No power is wasted on the carrier.
- A balanced modulator is a circuit used to produce the sum and difference frequencies of a DSSC signal but to cancel or balance out the carrier.
- DSB is not widely used because the signal is difficult to demodulate (recover) at the receiver.

3-5: Single-Sideband Modulation

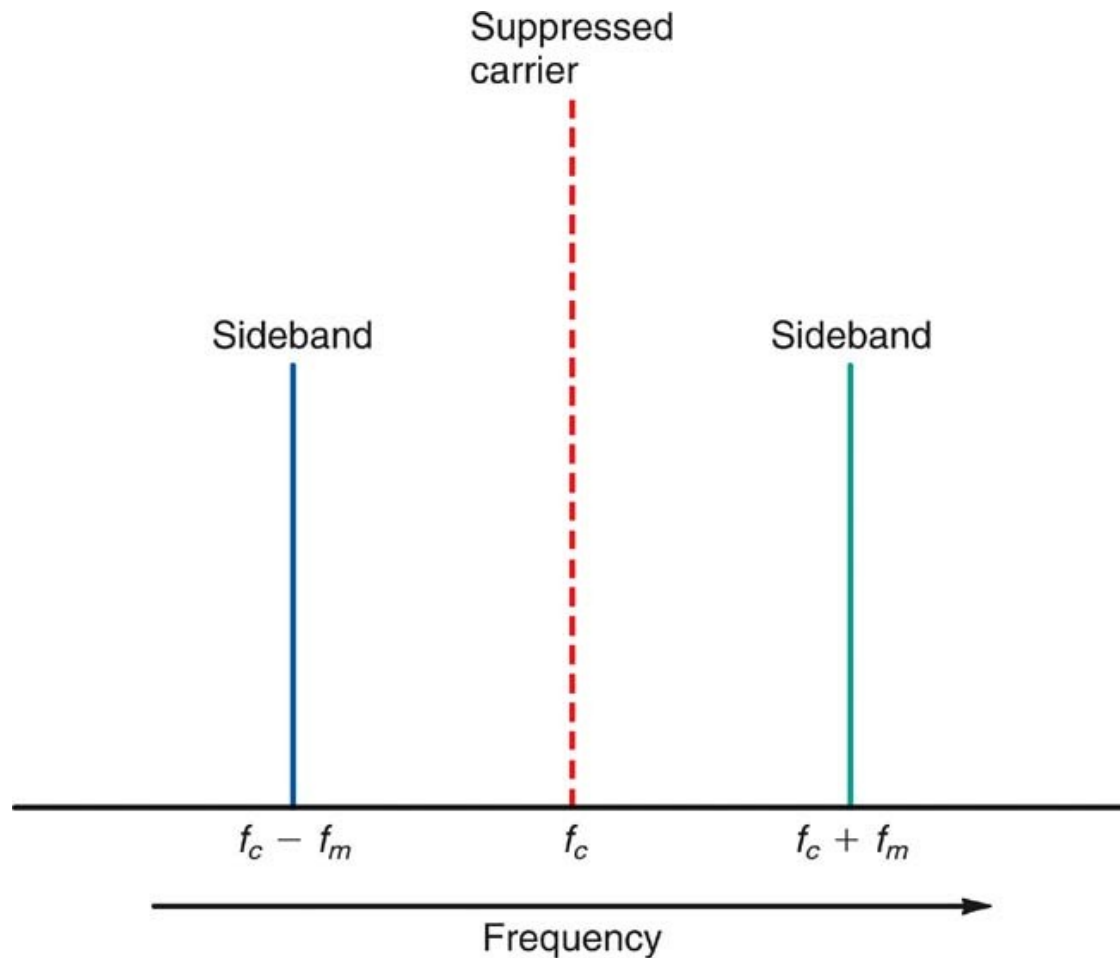


Figure 3-16: A frequency-domain display of DSB signal.

3-5: Single-Sideband Modulation

SSB Signals

- One sideband is all that is necessary to convey information in a signal.
- **A single-sideband suppressed carrier (SSSC)** signal is generated by suppressing the carrier and one sideband.

3-5: Single-Sideband Modulation

SSB Signals

- SSB signals offer four major benefits:
 1. Spectrum space is conserved and allows more signals to be transmitted in the same frequency range.
 2. All power is channeled into a single sideband. This produces a stronger signal that will carry farther and will be more reliably received at greater distances.
 3. Occupied bandwidth space is narrower and noise in the signal is reduced.
 4. There is less selective fading over long distances.

3-5: Single-Sideband Modulation

Disadvantages of DSB and SSB

- Single and double-sideband are not widely used because the signals are difficult to recover (i.e. demodulate) at the receiver.
- A low power, **pilot carrier** is sometimes transmitted along with sidebands in order to more easily recover the signal at the receiver.

3-5: Single-Sideband Modulation

Signal Power Considerations

- In SSB, the transmitter output is expressed in terms of **peak envelope power (PEP)**, the maximum power produced on voice amplitude peaks.

Applications of DSB and SSB

- A **vestigial sideband signal (VSB)** is produced by partially suppressing the lower sideband. This kind of signal is used in TV transmission.

Exercise (SOEC3.1P91)

- An audio signal $15\sin 2\pi(1500t)$
- Amplitude modulates a carrier $60\sin 2\pi(100000t)$
 - Sketch the audio signal
 - Sketch the carrier
 - Construct the modulated wave
 - Determine the modulation index and percent modulation
 - What are the frequencies of the audio signal and the carrier
 - What frequencies would show up in the spectrum analysis of the modulated wave.

Exercise (SOEC3.10P99)

- The total power content of an AM wave is 600W. Determine the percent modulation of the signal if each of the sidebands contains 75W.

Exercise (SOEC3.6P97)

- Determine the power content of the carrier and each of the sidebands for an AM signal having a percent modulation of 80% and the total power of 2500W.

Exercise (SOEC3.15P102)

- A single-sideband (SSB) signal contains 1kW. How much power is contained in the sidebands and how much at the carrier frequency?

3-6: Classification of Radio Emissions

- A code is used to designate the types of signals that can be transmitted by radio and wire.
- The code is made up of a capital letter and a number.
- Lowercase subscript letters are used for more specific definition.
- Examples of codes:
 - DSB two sidebands, full carrier = A3
 - DSB two sidebands, suppressed carrier = A3_b
 - OOK and ASK = A1

3-6: Classification of Radio Emissions

- The **International Telecommunications Union (ITU)**, a standards organization, uses a code to describe signals.
- Examples are:
 - A3F amplitude-modulated analog TV
 - J3E SSB voice
 - F2D FSK data
 - G7E phase-modulated voice, multiple signals

3-6: Classification of Radio Emissions

Letter	A	Amplitude modulation
	F	Frequency modulation
	P	Phase modulation
Number	0	Carrier ON only, no message (radio beacon)
	1	Carrier ON/OFF, no message (Morse code, radar)
	2	Carrier ON, keyed tone ON/OFF (code)
	3	Telephony, message as voice or music
	4	Fax, nonmoving graphics (slow-scan TV)
	5	Vestigial sideband (commercial TV)
	6	Four-frequency duplex telegraphy
	7	Multiple sidebands each with different message
	8	
Subscripts	9	General (all others)
	None	Double sideband, full carrier
	a	Single sideband, reduced carrier
	b	Double sideband, no carrier
	c	Vestigial sideband
	d	Carrier pulses only, pulse amplitude modulation (PAM)
	e	Carrier pulses only, pulse width modulation (PWM)
	f	Carrier pulses only, pulse position modulation (PPM)
	g	Quantized pulses, digital video
	h	Single sideband, full carrier
	j	Single sideband, no carrier

Figure 3-19: Radio emission code designations.

3-6: Classification of Radio Emissions

Type of Modulation	
N	Unmodulated carrier
A	Amplitude modulation
J	Single sideband
F	Frequency modulation
G	Phase modulation
P	Series of pulses, no modulation
Type of Modulating Signals	
0	None
1	Digital, single channel, no modulation
2	Digital, single channel, with modulation
3	Analog, single channel
7	Digital, two or more channels
8	Analog, two or more channels
9	Analog plus digital
Type of Intelligence Signal	
N	None
A	Telegraphy, human
B	Telegraphy, machine
C	Fax
D	Data, telemetry, control signals
E	Telephony (human voice)
F	Video, TV
W	Some combination of any of the above

Figure 3-20: ITU emissions designations.